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FIELD EVALUATION OF COMBUSTION AIR EFFECTS ON ATMOSPHERIC EMISSIONS FROM MUNICIPAL INCINERATORS

ROBERT A. TAFT SANITARY ENGINEERING CENTER
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by

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16. Abstracts

Field studies were conducted on two municipal incinerators with capacities of 50 tons and 250 tons per day in evaluating combustion air effects on atmospheric emissions from municipal incinerators. Separate tests were made at several different levels of underfire combustion air over as wide a range as operating conditions would permit. Solid particulate samples were collected under each test condition for comparison purposes. The results of these field tests show that 50 percent underfire and 50 percent overfire air approaches an ideal distribution, which keeps the particulate emissions well below the loadings which result when using a much higher percentage of underfire air. The following gaseous pollutants were measured for each furnace: Oxides of nitrogen, formaldehyde, carbon monoxide and hydrocarbons. Two schematic diagrams are included.

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A series of previously reported laboratory studies have been made to determine those factors of incinerator operation and design which affect the discharge of pollutants to the atmosphere. These tests, which were conducted in an experimental incinerator rated at 180 lbs/hr. (or slightly over 2 tons/day), have demonstrated that distribution of combustion air in the primary combustion chamber is a major factor affecting the discharge of fly ash and solid particulate matter to the atmosphere. Specifically, the tests showed that particulate emissions increased as the level of underfire* air was increased.

In one series of laboratory tests[1] the level of underfire combustion air was varied from 3 to 60 scfm/sq. ft. of grate area, and the resulting particulate emissions ranged from 1.6 to 8.6 lbs/ton of combustible material burned. The fuel used in this study was a mixture of newspaper, cardboard and wood chips. When a high ash content paper was substituted for the newspaper portion, a similar series of tests produced even higher particulate emissions, ranging from 3.2 to 35 lbs/ton of combustible material for the same range of underfire air flow rates.

In a second laboratory study[2] which was made to evaluate emissions produced by burning a high volatile material composed of asphalt felt roofing and newspaper, tests were made under conditions in which the level of underfire air was varied while all other variables were held constant, and the resulting particulate emissions increased from 5.3 to 19.8 lbs/ton of fuel burned. In this case, the level of underfire air ranged from 6 to 34 scfm/sq. ft. of grate area on tests made at 100 per cent excess combustion air. With 200 per cent excess air, particulate emissions increased from 11.2 to 47.2/lbs/ton of material burned when underfire air was varied from 8.5 to 50 scfm/sq. ft. of grate area. A plot of the data obtained from the forementioned tests is shown in Figure 1.

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*Underfire air is that portion of the total combustion air which is introduced under the grate and passes up through the burning fuel bed.

In view of this consistent trend in all of the laboratory tests involving the experimental incinerator, a sequence of field tests have been made on full scale incinerators in order to determine the extent to which this relationship between underfire air and particulate emissions applies to incinerators of different sizes and designs. Of particular interest were large municipal type units where the increase in furnace size over the relatively small experimental unit was considerable (Table 1). Under such circumstances, direct extrapolation of the underfire air effect to larger units might be subject to the introduction of additional factors that could conceivably modify or even invalidate the relationships developed on the small unit.

The field studies reported were conducted on two municipal incinerators having rated furnace capacities of 50 tons and 250 tons per 24 hour day. Both units were operated under essentially normal conditions during each test. Separate tests were made at several different levels of underfire combustion air over as wide a range as operating conditions would permit, and solid particulate samples were collected under each test condition for comparison purposes.

Fifty-ton per day batch charge incinerator

One series of tests was made on a medium-sized municipal incinerator having a 50-ton per 24 hour day multiple chamber furnace. Refuse was charged on a batch basis with the material being introduced at the front end of the ignition chamber (Figure 2). Reciprocating stoker grates moved the burning fuel to the rear of the combustion chamber at which point the ashes dropped to a water quench. Combustion gases were diluted with air after leaving the secondary combustion chamber, passed through a water spray scrubber and then to an induced draft fan for discharge to atmosphere.

Underfire air was supplied by a forced draft fan discharging to a single compartment under the grate. Overfire air entered as leakage through cracks around the charging door and through stoking door ports. On tests made at higher-than-normal levels of overfire air (low underfire) the charging door was left partly open to provide an access port for the required volume of overfire air. This was a particularly advantageous method of introducing overfire air as it thus swept across the surface of the fuel bed providing good contact with the burning refuse.

Under normal conditions this furnace operated with approximately 40 to 60 per cent of the primary chamber combustion air being introduced as underfire air. Under the conditions of these tests, the furnace was operated at three different underfire air levels as follows: 20, 50 and 70 per cent underfire air.

The effect of different amounts of underfire air in producing particulate emissions was determined by collecting particulate samples at sampling position No. 1 in the breeching as shown in Figure 2. Details of the sampling procedure have been described previously.(3)

Refuse burned at this plant was typical of the material collected from residential and commercial sources in a small community - in this case a town having a population of 12,000. During the tests, moisture content of the material varied roughly from 15 to 35 per cent by weight, which is a usual range for this type of refuse.

250-ton per day continuous feed incinerator

A second series of tests was carried out on a 250-ton per 24 hour day unit operated by a large municipality. As shown on the schematic drawing (Figure 3) this incinerator employs a continuous refuse feed into one end of the furnace, and the material burns on a conveyor-type grate which discharges ashes into a water quench at the far end of the combustion chamber. Combustion gases pass from the primary chamber to the secondary chamber and then into the breeching, the downstream section of which forms an expansion chamber. From here the gases pass into the stack and are discharged to the atmosphere. From the standpoint of maintaining uniform combustion conditions, continuous refuse feed into the front end of the primary combustion chamber and a continuous discharge of the residue at the rear end is considered as being much superior to the batch charge method.

Under normal conditions this furnace operated with approximately 80 per cent of the primary chamber combustion air being supplied as underfire air. A forced draft fan discharges air to a series of windboxes under the grate thereby permitting underfire combustion air to be distributed as required along the length of the burning bed. Overfire air, also supplied by the forced draft blower, is introduced through side ports and through duct openings in the top of the primary combustion chamber. Some air leakage into the primary chamber occurs at the stoking doors, around the charging grate and at the front end of the burning grate.

Separate tests were carried out with approximately 20, 50, 80 and 100 per cent of the combustion air in the primary chamber being supplied as underfire air. The balance in each case was furnished as overfire air introduced through the wall and roof ports. Distribution between overfire and underfire air was accomplished by adjusting dampers in the appropriate air ducts.

The refuse burned at this plant was typical of material obtained from a residential neighborhood in a large metropolitan city. The refuse generally had a moisture content ranging from 25 to 40 per cent by weight and an inert content of about 20 per cent by weight.

The effect of the various levels of underfire combustion air on particulate emissions was again determined by collecting particulate samples from the breeching, well beyond the secondary combustion chamber as shown in Figure 3. In this case, the shape of the gas velocity profile in the 12 ft. high breeching dictated the desirability of collecting double samples in order to get a true representation of the particulate loadings. Samples on all tests were therefore collected at average velocity positions for the top and bottom sections of the velocity profile. To accomplish this, two sampling probes were operated simultaneously, and the eight foot wide breeching was traversed using four sampling points at each level. Sampling techniques already described[3] were used for collection of samples.

RESULTS - PARTICULATE EMISSIONS

Fifty-ton per day unit

Tests made on this unit were grouped for comparison into three levels of underfire air which averaged 11, 30 and 40 scfm/sq. ft. of grate area. Particulate emissions at these levels as shown in Table 2 averaged 0.78, 1.04 and 1.79 lbs/1000 lbs. dry flue gas corrected to 50 per cent excess combustion air.* From these values it is seen that the initial increase of 172 per cent in underfire air produced only a 33 per cent increase in particulate emissions from the furnace, but with a further increase of 33 per cent in underfire air (from 30 to 40 scfm/sq. ft.), the particulate emissions increased an additional 96 per cent. This trend is illustrated in Figure 4 which shows a plot of the individual values.

While the effect of underfire air in increasing particulate emissions appears to be less pronounced at the lower levels of underfire air in this furnace than in the experimental unit, it will be noted from the appropriate curve in Figure 4 that there is a significant increase in loadings when underfire air is increased from 30 to 40 scfm/sq. ft. of grate area. Limitations of the air supply system and other operational factors prevented testing higher underfire air rates on this furnace, but it is reasonable to expect that additional increases in underfire air would have produced even higher particulate emissions.

As would be expected, the different levels of underfire air had a distinct effect on the refuse burning rate. With normal operation involving approximately 50 per cent underfire air, the amount of material charged to the furnace averaged 46.2 tons per 24 hour day. When underfire air was

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*All loadings reported in lbs./1000 lbs. flue gas are on a dry basis and corrected to 50% excess combustion air.

reduced to 18 per cent of the total combustion air, the average refuse charging rate dropped to 33.7 tons per 24-hour day, a reduction of 27 per cent. At the high underfire air rate involving the use of 70 per cent underfire air, the fuel charging rate averaged 48.2 tons per 24 hour day. At this high level of underfire air, the charging rate was necessarily limited in order to prevent excessively high temperatures in the furnace.

250-ton per day furnace

Tests on this unit were made at four levels of underfire air which averaged 9, 21, 35 and 40 scfm/sq. ft. of grate area. The corresponding particulate emissions as shown in Table 3 averaged 3.8, 2.8, 3.3, and 4.6 lbs. of particulate per 1000 lbs. dry flue gas corrected to 50 per cent excess combustion air.

In contrast to the results obtained at the low underfire air conditions on both the experimental incinerator and the 50-ton per day unit, the 3.8 lb. loading which occurred on this large furnace at the 20 per cent underfire air level (9 scfm/sq. ft. grate area), was higher than the average loadings produced at either the 50 or 80 per cent underfire air levels.

Although this emission rate suggests a reversal of the trend established in the other units, an evaluation of the furnace conditions which prevailed during this set of tests, indicates that factors other than underfire air contributed to this high emission rate. The furnace and combustion conditions which occurred during the 20 per cent underfire air tests were noticeably different from the optimum conditions attained on the other tests and provide a logical explanation of this unexpectedly high loading at the low underfire air level. Of primary importance are the following factors:

1. The furnace, which was normally operated with 80 per cent underfire air, was not designed for the introduction of large volumes of overfire air into the primary combustion chamber. Consequently, on the 20 per cent underfire tests it was necessary to introduce 80 per cent of the total combustion air into the furnace through a number of relatively small roof and wall ports. The pressure required to provide the necessary air volume through these small ports produced a series of air jets discharging from the top and from both sides at the front end of the furnace. These air jets caused a high degree of turbulence in the combustion chamber with resultant agitation and churning of material on the surface of the fuel bed. This excessive turbulence could account for an increase in the amount of suspended particulate material in the gas stream and thereby explain the high loadings obtained.

2. A second factor involved the method of burning and the rate at which refuse was charged to the furnace on this set of tests. In order to maintain a furnace temperature above 1600°F. at the 20 per cent underfire air condition, it was necessary to maintain a fuel feed rate in excess of that which would allow complete combustion of material on the grate. This resulted in a lower quality of incinerator residue than occurred under the other test conditions. Burning of the volatiles was also less complete due to the cooling effect produced at the top of the combustion chamber by the introduction of 80 per cent overfire air at the sides and top of the furnace. This excessive cooling produced an orange flame throughout the combustion chamber during most of the test period, a situation which indicates less than ideal combustion conditions and introduces another possibility for increased particulate loadings.

3. The third factor which could have contributed to increased particulate loadings involved stoking and raking of the fuel bed. With only 20 per cent underfire air, burning was predominantly a surface ignition process with the result that any compacted material on the grate had to be stirred up to promote its burning. With the deeper fuel bed resulting from the comparatively high refuse feed rate, attainment of any degree of complete combustion required considerably more stoking and raking of the refuse on the grate than was required on other test conditions. This continual disturbance combined with the previously described excessive gas turbulence provided ideal conditions for increasing the particulate loading of the gas stream.

Since these factors indicate that the furnace design mitigated against proper combustion at the 20 per cent underfire air level, it seems logical to exclude these tests from further consideration, and to analyze the remaining data on the basis of underfire air since combustion conditions achieved in all other tests occurred under more or less optimum conditions based on visual observation of the furnace.

By reference to the underfire air flow rates and the corresponding particulate loadings for the three higher levels of underfire air shown in Table 3, it will be noted that a 67 per cent increase in underfire air (from 21 to 35 scfm/sq. ft.) produced only an 18 per cent increase in particulates, but a further increase of 14 per cent underfire air (from 35 to 40 scfm/sq. ft.) produced a 39 per cent increase in loadings. As was the case in the 50-ton per day unit, a significant increase in the emission loadings occurred between 35 and 40 scfm/sq. ft. of grate area. This trend is shown in the plot of data in Figure 4.

The effect of different underfire air levels on the refuse burning rate for this furnace was essentially the same as on the 50-ton unit. At the 80 per cent underfire air level, the average refuse charging rate to the furnace was maintained at approximately 270 tons per day, or 8 per cent above the 250-ton rated capacity. This condition produced an average temperature in the secondary chamber above 1900°F. At 100 per cent underfire air the same temperature range resulted while charging only 220 tons per day or

12 per cent less than rated capacity. Under this condition the charging rate was necessarily restricted to prevent excessive temperatures in the furnace. The refuse charging rate on the 50 per cent underfire air tests was 232 tons per day which is 7 per cent below rated capacity. This condition produced temperatures slightly below 1800°F. This lower burning rate at 50 per cent underfire air was partly due to the fact that half of the tests at this condition were conducted with refuse having an above-average moisture content. Operation of the furnace with only 20 per cent underfire air required that the refuse charging rate be maintained at the expense of burning rate, a condition which resulted in incompletely burned material being discharged at the end of the grate. A rate of 266 tons per day was maintained and temperatures averaged between 1700 and 1800°F.

ADDITIONAL RESULTS

Although the main objective of these field tests was to measure the effect of underfire combustion air on the production of particulate emissions, additional information was collected to provide other comparative data on the field operated municipal units and the small experimental incinerator:

1. Measurement of gaseous pollutants including oxides of nitrogen, total hydrocarbons, formaldehyde and carbon monoxide.

2. Determination of the effectiveness of the water spray scrubber on the 50-ton unit in reducing both gaseous and particulate emissions.

Oxides of Nitrogen*

On the 50-ton per day furnace the oxides of nitrogen emission rate followed previously established trends[1] by increasing at the higher excess air levels as shown in Figure 5. From the data contained in Table 2, it will be noted that the average loading of 0.16 lbs./1000 lbs. dry flue gas which occurred on tests averaging 100 per cent excess air increased by 137 per cent to 0.38 lbs./1000 lbs. dry flue gas on tests averaging 235 per cent excess air.

On the 250-ton per day furnace, all tests were made at essentially the same general level of excess air, providing no comparative data between the excess air levels on this furnace. However, effect of the underfire-overfire

*Oxides of nitrogen were determined by collection of integrated grab samples[1] with analysis by the Saltzman modification of the Greiss colorimetric technique.

air ratio on the NO_2* emission rate was quite pronounced as shown by the graph of Figure 6. Table 3 shows that the maximum NO_2 emission rate of 0.33 lbs./1000 lbs. dry flue gas which was produced at the 20 per cent underfire air level was 65 per cent higher than the 0.20 lbs./1000 lbs. dry flue gas produced at the 100 per cent underfire air level.

Higher NO_2 loadings resulting from tests made with low underfire (high overfire) air ratios can be attributed to the manner in which burning takes place under the two extremes tested on the 250-ton per day furnace. At the 100 per cent underfire air condition, there is an early depletion of the oxygen content of incoming air due to rapid burning of both volatiles and fixed carbon in the bed and immediately above the bed. Under the opposite condition involving high overfire (20% underfire), oxygen consumption is slower since the combustion air introduced at the top of the furnace is in less intimate contact with the burning fuel bed as it enters the furnace and therefore exists in the high temperature zone at a comparatively high O_2/N_2 ratio for a longer time interval.

The data in Table 4 comparing NO_2 loadings based on the amount of refuse charged to the incinerator shows that the emission rate of NO_2 per pound of refuse burned is about the same from both sizes of incinerators.

Formaldehyde

Formaldehyde concentrations were measured by a previously described technique(2) involving the bubbling of a sample gas stream through chromatropic acid solution. Emissions from both the 50-ton and the 250-ton units were higher at the lower furnace temperatures. Since temperatures generally increased as underfire air increased, the maximum formaldehyde emissions occurred at the lower underfire air levels. The relationship established between formaldehyde emissions and furnace temperature confirms the data obtained on the experimental unit. On the 50-ton furnace, there was no measurable formaldehyde at the highest underfire air level (70%), but the 20% underfire tests produced an average of 9.9×10^{-4} lbs./1000 lbs. dry flue gas as shown in Table 2.

On the 250-ton per day furnace the 100 per cent underfire air level produced 1.7×10^{-4} lbs./1000 lbs. dry flue gas, but this emission rate increased by 65 per cent at the 50 per cent underfire condition, and by 130 per cent (to 3.9×10^{-4} lbs./1000 lbs. dry flue gas) at the 20 per cent underfire condition (Table 3).

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*The symbol NO_2 is used throughout this discussion to denote oxides of nitrogen, which are determined as equivalent NO_2.

Carbon Monoxide

On both furnaces, the concentration of carbon monoxide was too low to be measured using a standard orsat technique. A nondispersive infrared gas analyzer having a full-scale range of 0 to 5 per cent gave readings slightly above the limit of detectability on the 50-ton per day furnace. Measurement of carbon monoxide concentrations on the 250-ton per day unit was possible only by using a stain-in-tube type gas detector having a range of 10 to 2000 ppm. Emissions of carbon monoxide reported in Tables 2 and 3 were based on these methods of analysis. It will be noted that the highest carbon monoxide emission of 1.0 lb./1000 lbs. dry flue gas occurred on the 50-ton unit at the test condition which produced the lowest average temperature.

Carbon monoxide emissions from the 250-ton unit ranged from 0.03 to 0.07 lbs./1000 lbs. dry flue gas with no definite trend indicated. The test conditions established in this furnace involving high temperatures and high excess air levels would be expected to produce a minimum of carbon monoxide.

Hydrocarbons

The total organic content of flue gases in the 250-ton furnace was continuously monitored using a nondispersive hexane sensitized infrared gas analyzer having a range of 0 to 750 ppm hydrocarbon measured as hexane. In all tests on this furnace the hydrocarbon concentration was below the 15 ppm limit of detectability of this instrument. The hydrocarbon loadings reported in Table 3 for the 250-ton unit are based on this limit.

On the 50-ton furnace, integrated bag samples taken on the tests involving 50 per cent air distribution, were analyzed by a flame ionization detector having a sensitivity of 4 ppm carbon (0.7 ppm hexane). Hydrocarbon concentrations were found to be below the 4 ppm carbon limit of detectability of this analyzer. The emission rate reported in Table 2 as being less than 0.003 lbs./1000 lbs. dry flue gas is based on this analysis.

Effect of Water Spray Scrubber on 50-ton per day furnace

The efficiency of the water spray scrubber in removing solid particulates and gaseous contaminants from the gas stream of the 50-ton furnace was measured by collecting simultaneous samples both before and after the scrubber as shown in Figure 2.

The average particulate discharge ahead of the scrubber had a 130 per cent variation, ranging from 0.78 to 1.79 lbs./1000 lbs. dry flue gas, whereas the average discharge after the scrubber varied from 0.55 to 0.61 lbs./1000 lbs. dry flue gas which is only a difference of 11 per cent. The fact that the scrubber reduces the particulate discharge to a relatively constant level, even though loadings ahead of the scrubber may vary considerably, indicates the efficiency is related to particle size of the solid emissions.

As shown in Table 2, there was a slight reduction in the formaldehyde emission rate after flue gases passed through the spray scrubber, but there was no reduction in the NO_2 emission rate.

DISCUSSION

The difference in the underfire air effect on particulate emissions between the small experimental incinerator and the larger field units suggests that each size and design of incinerator furnace has a characteristic trend which is a function of volume, combustion chamber geometry, gas velocity and turbulence, and possibly other factors.

Levels of underfire air tested on the small experimental unit ranged from 3 to 100 scfm/sq. ft. of grate area while the levels tested on the larger units covered a narrower span, ranging from 11 to 40 scfm/sq. ft. on the 50-ton unit and from 9 to 40 scfm/sq. ft. on the 250-ton unit. Although operational limitations of the larger field incinerators prevented testing at higher levels of underfire air, it is logical to assume that the use of higher underfire air rates in these furnaces would have produced appreciably higher loadings on both units.

The increase in NO_2 emissions which resulted at the higher excess air levels on the 50-ton per day furnace confirmed a similar trend produced in the experimental incinerator on previous studies.[1,2]

The relationship between NO_2 emission rate and the underfire air ratio which occurred on the 250-ton per day furnace appears to be a function of the furnace size and the location at which overfire combustion air was introduced into the furnace. This correlation did not occur on either the small unit or the 50-ton unit. Overfire combustion air was introduced into the 250-ton unit at the top and along the sides of the furnace chamber under conditions which gave relatively poor contact between air and fuel. By contrast, overfire combustion air introduced into both the experimental unit and the 50-ton per day municipal unit was passed through the refuse charging door at the front end of the furnace in a manner which permitted the inflowing air to sweep across the burning fuel bed, thus providing the best possible contact between overfire air and fuel.

CONCLUSIONS AND RECOMMENDATIONS

The trend towards higher particulate emissions with increased underfire air was less pronounced in the two municipal incinerators tested than in the small experimental incinerator; however, there does appear to be a critical level of underfire air for the larger units beyond which particulate emissions do increase significantly. On the two units tested this change in trend occurred at an underfire airflow between 35 and 40 scfm/sq. ft. of grate area.

In the interest of reducing particulate emissions from small incinerators, 10 to 20 per cent underfire combustion air has been recommended[2,4] as a suitable amount for units burning bulky and relatively dry material (up to 25% moisture). However, on these larger units burning municipal refuse of nonhomogeneous composition and moisture content ranging up to 40 per cent, the application of only 20 per cent underfire air causes an appreciable reduction in the refuse burning rate but does not produce drastic reductions in particulate emissions.

Based on the results of these field tests, it would appear that the use of approximately 50 per cent overfire and 50 per cent underfire air approaches an ideal distribution which permits the furnace to operate satisfactorily in terms of providing the maximum burning rate for municipal refuse subject to normal variations in compaction and moisture (up to 40%) content, and at the same time keeps the particulate emissions well below the loadings which result when using a much higher percentage of underfire air.

Use of 70 per cent or more underfire air on medium-sized units and use of close to 100 per cent underfire air on the largest units would be expected to produce abnormally high particulate emissions without necessarily increasing the burning rate beyond that attainable with 50 per cent underfire air. These limits apply to the burning of refuse which has a moisture content ranging up to 40 per cent. Material containing more than 50 per cent moisture will necessarily require higher levels of underfire air to maintain combustion, and when refuse has been wet by rainfall, burning will have to be maintained with whatever amount of underfire air is required--at the expense of increased particulate emissions to the atmosphere.

The introduction of overfire combustion air at the front end of the furnace and on a level with the burning fuel bed appears to provide the best contact between overfire air and fuel, and in the larger incinerators this arrangement would be most likely to keep NO_2 emissions to a minimum.

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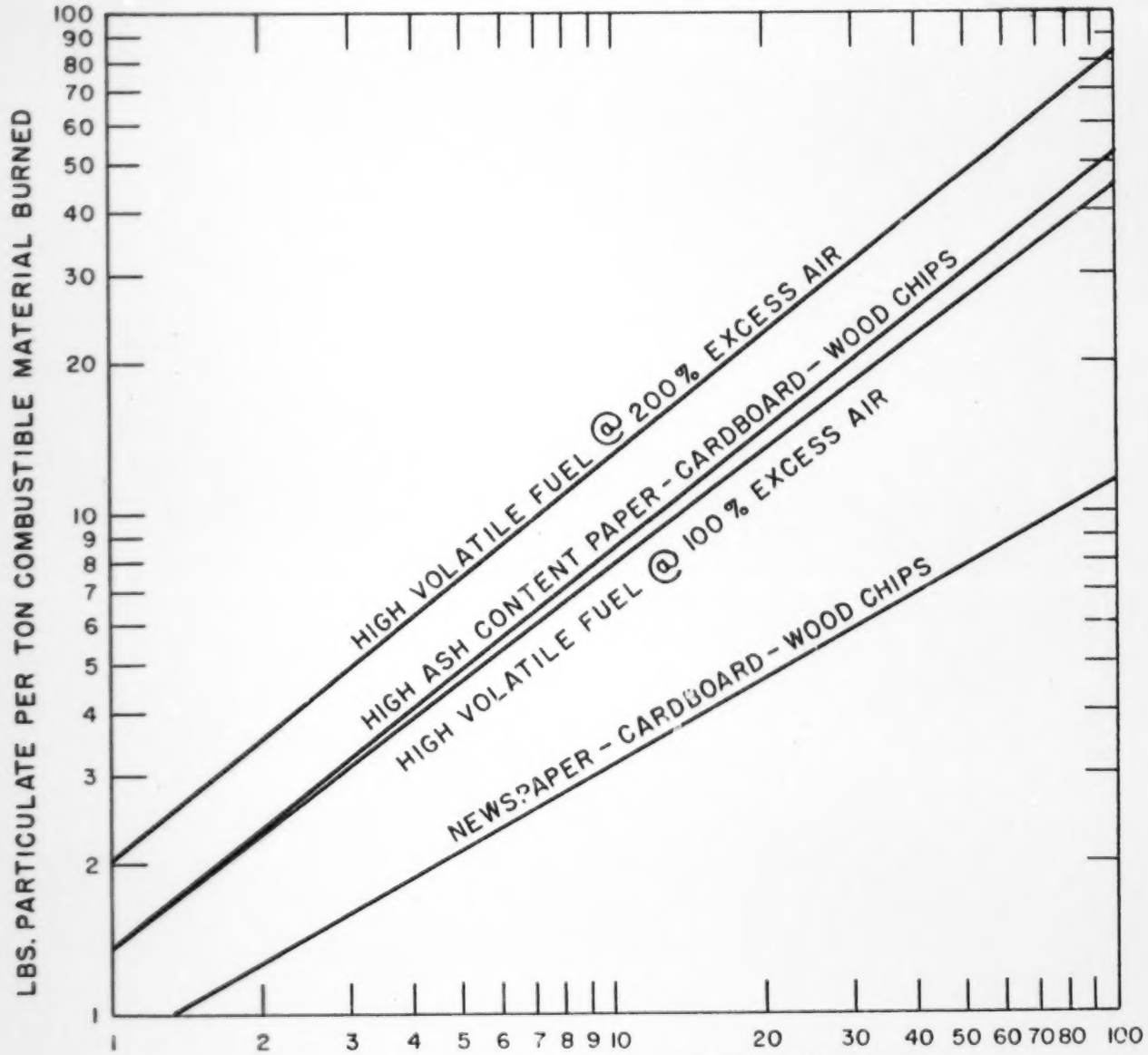
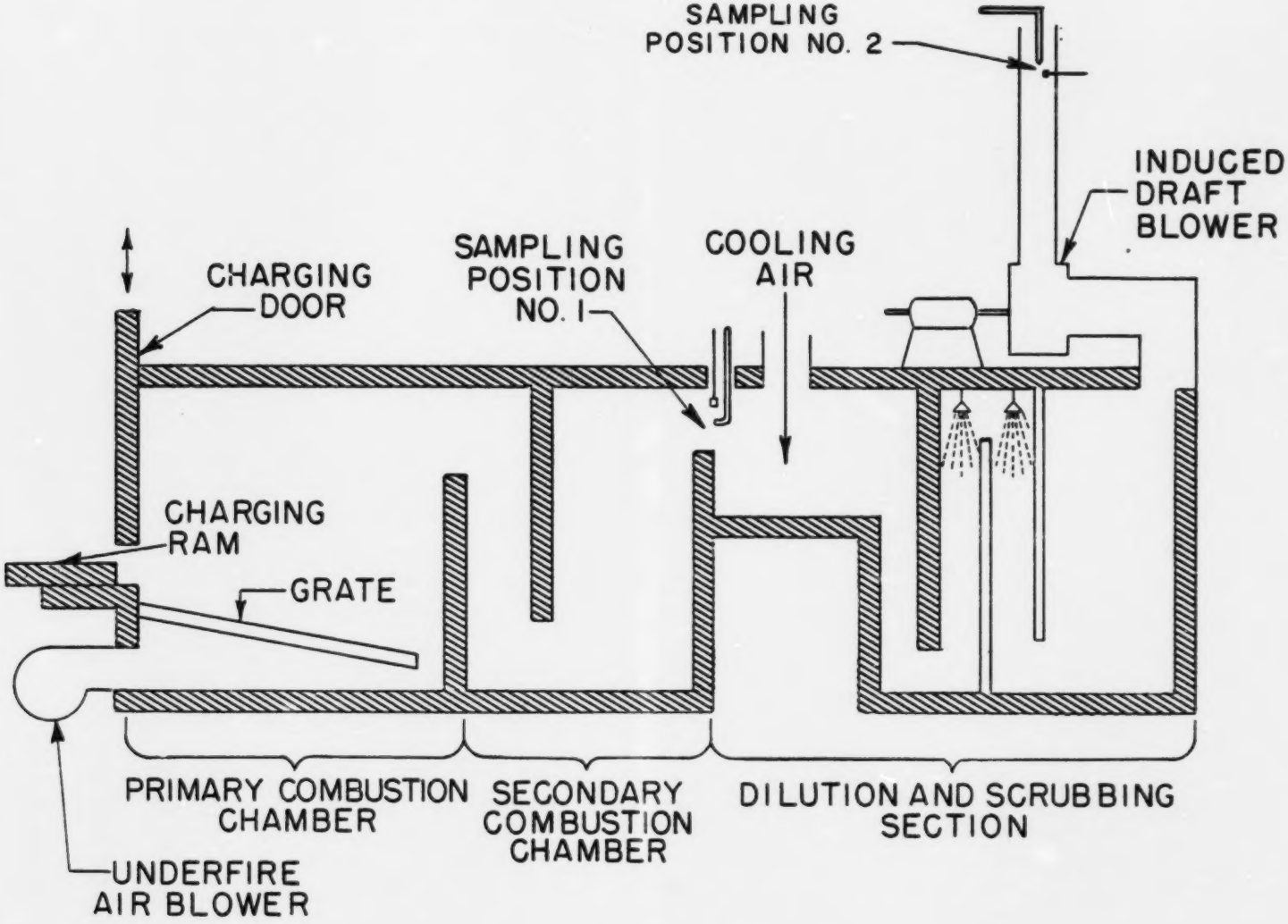


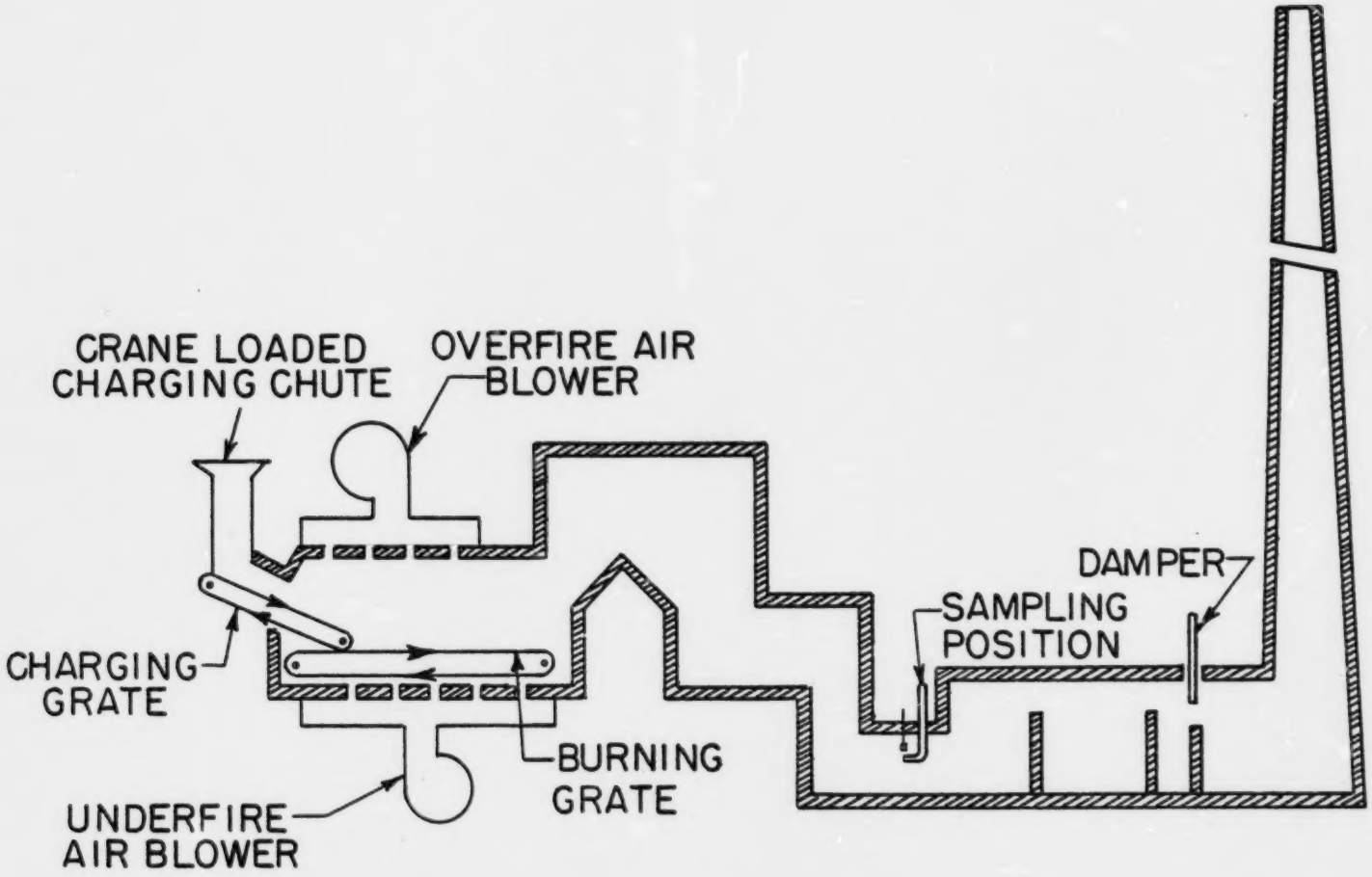
RELATIONSHIP OF PARTICULATE DISCHARGE TO UNDERFIRE AIR — 2-TON / DAY EXPERIMENTAL INCINERATOR

FIGURE 1



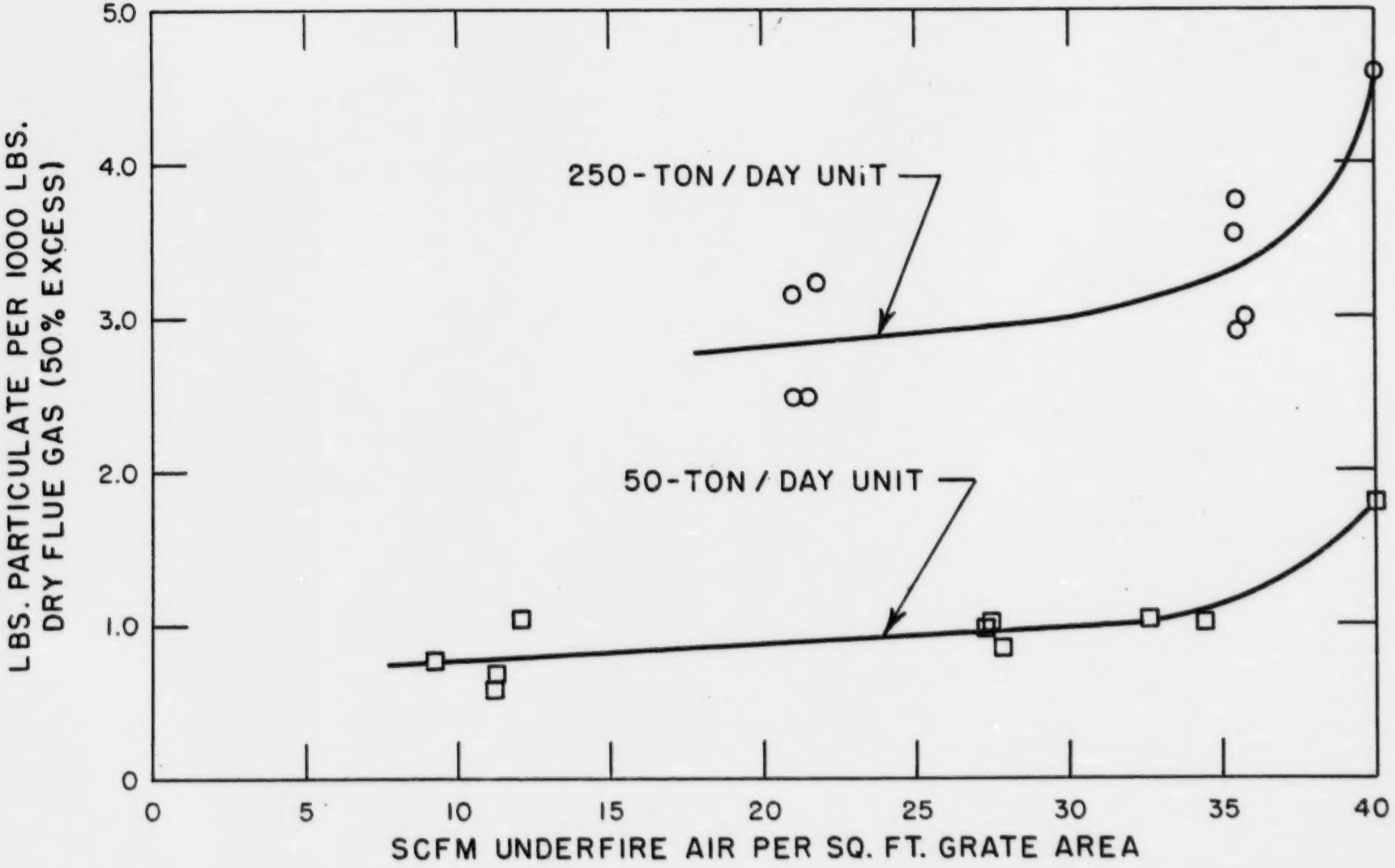
SCHEMATIC ELEVATION OF 50 TON PER DAY
BATCH CHARGE MUNICIPAL INCINERATOR

FIGURE 2



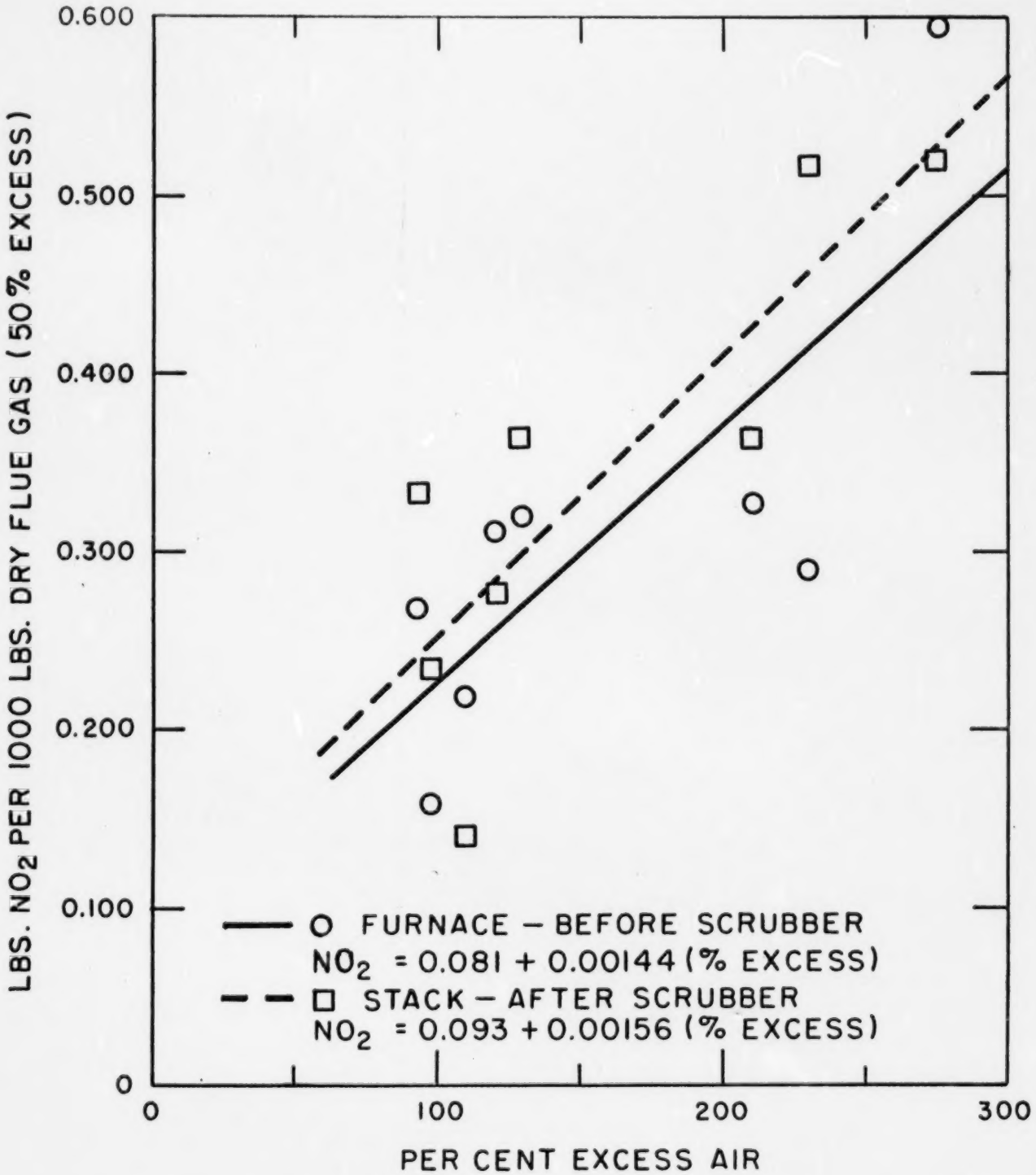
SCHEMATIC DIAGRAM OF 250 TON PER DAY
CONTINUOUS FEED MUNICIPAL INCINERATOR

FIGURE 3



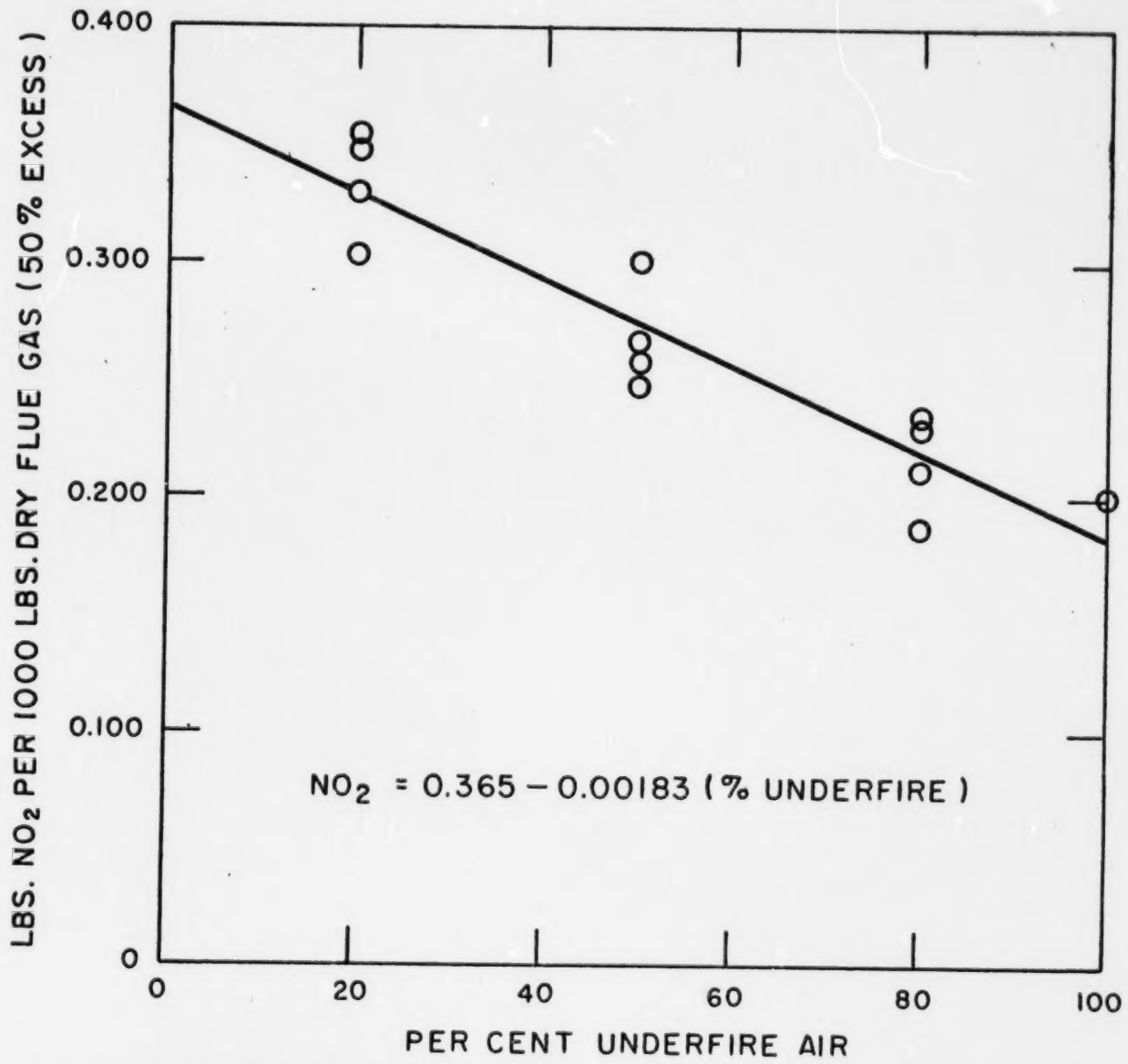
RELATIONSHIP OF PARTICULATE DISCHARGE TO UNDERFIRE AIR

FIGURE 4



RELATIONSHIP BETWEEN OXIDES OF NITROGEN AND EXCESS AIR — 50-TON / DAY UNIT

FIGURE 5



RELATIONSHIP BETWEEN OXIDES OF NITROGEN AND UNDERFIRE AIR — 250-TON / DAY UNIT

FIGURE 6

TABLE 1

SUMMARY OF FURNACE DIMENSIONS AND GRATE LOADINGS

PRIMARY COMBUSTION CHAMBER	RATED CAPACITY (Tons/24 Hour Day)		
	2 1/	50 2/	250 3/
Length to width ratio	2	2.6	5.4
Arch Height Above Grate (feet)	2.7	7 to 8.5	14
Volume (cubic feet)	19.5	675	4150
Volume Ratio of Primary to Secondary Combustion Chambers	1.1	2.8	0.6
Grate Area (sq. feet)	8.5	85.5	288
Grate Loading (Rated Capacity in lbs./sq.ft./hour)	21.2	41.6	72
Grate Loading (During test conditions in lbs./sq.ft/hour)	17 to 28	30 to 52	63 to 83

1/ Experimental Incinerator.

2/ Batch Charge Municipal Incinerator.

3/ Continuous Feed Municipal Incinerator.

TABLE 2

SUMMARY OF AVERAGE EMISSIONS FROM 50-TON/DAY BATCH CHARGE FURNACE

COMBUSTION CONDITIONS			LBS/1000 LBS. DRY FLUE GAS (Corrected to 50% Excess Air)							
UNDER-FIRE AIR (%)	EXCESS AIR (%)	TEMP. IN SECONDARY CHAMBER (°F.)	SOLID PARTICULATE		HYDRO-CARBONS (As Hexane)	CARBON MONOXIDE	OXIDES OF NITROGEN*		FORMALDEHYDE	
			1	2	1	1	1	2	1	2
20	235	1080	0.78	0.57	--	1.0	0.38	0.46	9.9×10^{-4}	7.2×10^{-4}
50	110	1500	1.04	0.55	< 0.003	0.2	0.28	0.25	2.2×10^{-4}	0.0×10^{-4}
70	100	1500	1.79	0.61	--	0.3	0.16	0.23	0.0×10^{-4}	0.0×10^{-4}

* Measured as NO_2

1 - From sampling point ahead of water spray scrubber.
2 - From sampling point after water spray scrubber.

TABLE 3

SUMMARY OF AVERAGE EMISSIONS FROM 250-TON/DAY CONTINUOUS FEED FURNACE

COMBUSTION CONDITIONS			LBS./1000 LBS. DRY FLUE GAS (CORRECTED TO 50% EXCESS AIR)				
Underfire Air (%)	Excess Air* (%)	Gas Temp. Sec. Chamb. (°F.)	Solid Particulate	Hydro-carbons (as Hexane)	Carbon Monoxide	Oxides of Nitrogen**	Formal-dehyde
20	190	1750	3.8	< 0.08	0.05	0.33	3.9×10^{-4}
50	180	1790	2.8	< 0.08	0.05	0.27	2.8×10^{-4}
80	190	1930	3.3	< 0.08	0.07	0.22	1.7×10^{-4}
100	150	1960	4.6	< 0.08	0.03	0.20	1.7×10^{-4}

* At sampling point in breeching.

** Measured as NO_2.

TABLE 4

SUMMARY OF EMISSIONS BASED ON AMOUNT OF REFUSE BURNED

INCINERATOR CAPACITY (Tons/Day)	COMBUSTION CONDITIONS		OXIDES OF NITROGEN (Lbs/Ton of Refuse Burned)		PARTICULATES (Lbs/Ton of Refuse Burned)	
	Excess Air* (%)	Underfire Air (%)	1	2	1	2
50 3/	215	20	3.2	3.3	6.1	4.1
	110	55	2.3	2.3	8.6	4.7
	100	60	1.4	2.2	15.5	5.7
250 4/	190	20	3.0			
	180	50	3.1			
	190	80	2.2			
	150	100	2.5			

* At sampling point in breeching for 250-ton/day unit.

1 - Sample ahead of water spray scrubber.

2 - Sample after water spray scrubber.

3/ - Batch Charge Municipal Incinerator.

4/ - Continuous Feed Municipal Incinerator.